

## What is Claimed:

- 1                   1.       A method for desalinating a solution containing sparingly soluble  
2       solute comprising the steps of:
  - 3                   (a)       introducing a solution having sparingly soluble solutes and  
4       nucleation crystals to the high pressure side of a first semi-permeable  
5       membrane barrier to produce a retentate stream on the high pressure side of  
6       the first semi-permeable membrane barrier, and a permeate stream on the low  
7       pressure side of the first semi-permeable membrane barrier having reduced  
8       concentrations of the sparingly soluble solutes;
  - 9                   (b)       introducing the permeate stream produced in step (a) to the high  
10       pressure side of a second semi-permeable membrane barrier to produce a  
11       second retentate stream on the high pressure side of the second semi-  
12       permeable membrane barrier, and a product stream on the low pressure side of  
13       the second semi-permeable membrane barrier with substantially lower  
14       concentrations of sparingly soluble and soluble solutes compared to the solution  
15       initially introduced in step (a); and
  - 16                   (c)       returning a majority fraction of the retentate stream rejected by  
17       the first semi-permeable membrane barrier containing a majority of the  
18       nucleation crystals to the solution that is introduced to the high pressure side of  
19       the first semi-permeable membrane barrier.
- 1                   2.       The method of claim 1 further comprising the step:
  - 2                   (d)       returning a majority fraction of the second retentate stream  
3       rejected by the second semi-permeable membrane barrier to the solution that  
4       is introduced into the high pressure side of the first semi-permeable  
5       membrane barrier.
- 1                   3.       The method of claim 1 wherein the initial solution is a heated  
2       saline solution.
- 1                   4.       The method of claim 1 wherein a portion of the solution  
2       introduced to the high pressure side of the first semi-permeable membrane  
3       barrier in step (a) is bypassed around the first semi-permeable membrane

4 barrier and is introduced to the high pressure side of the second semi-  
5 permeable membrane barrier.

1 5. The method of claim 1 wherein a majority fraction of the  
2 retentate stream rejected by the first semi-permeable membrane barrier  
3 containing a majority of the nucleation crystals is desupersaturated before said  
4 stream is returned to the solution introduced to the high pressure side of the  
5 first semi-permeable membrane barrier.

1 6. The method of claim 1 wherein the first semi-permeable  
2 membrane barrier is a nanofiltration membrane.

1 7. The method of claim 1 wherein the second semi-permeable  
2 membrane barrier is a reverse osmosis membrane.

1 8. The method of claim 1 wherein the first semi-permeable  
2 membrane barrier is contained in tubular membrane modules.

1 9. The method of claim 1 wherein the second semi-permeable  
2 membrane barrier is contained in spiral-wound membrane elements.

1 10. The method of claim 1 wherein the sparingly soluble solutes in  
2 the initial solution include calcium, sulfate and silica.

1 11. The method of claim 1 wherein the nucleation crystals in the  
2 solution of step (a) which is added to the high pressure side of the first semi-  
3 permeable membrane barrier are added to the solution upon startup, and are  
4 selected from the group consisting of calcium sulfate, calcium carbonate,  
5 calcium phosphate, and silica.

1 12. The method of claim 1 wherein the initial solution is a saline  
2 solution comprised of water containing between 3,000 and 20,000 mg/L of total  
3 dissolved solids.

1 13. The method of claim 1 wherein the solution produced on the low  
2 pressure side of the second semi-permeable membrane barrier is water  
3 containing less than 500 mg/L of total dissolved solids.

1 14. The method of claim 1 wherein the water content of the product  
2 stream produced on the low pressure side of the second semi-permeable  
3 membrane barrier is greater than or equal to 80% of the water content of the

4 solution introduced to the high pressure side of the first semi-permeable  
5 membrane barrier.

1 15. The method of claim 1 wherein the solution introduced to the  
2 high pressure side of the first semi-permeable membrane barrier is agricultural  
3 drainage water.

1 16. The method of claim 1 wherein the solution introduced to the  
2 high pressure side of the first semi-permeable membrane barrier is  
3 groundwater.

1 17. The method of claim 1 wherein the solution introduced to the  
2 high pressure side of the first semi-permeable membrane barrier is a brine  
3 stream produced in a separate water treatment process.

1 18. A method of desalinating a saline solution containing sparingly  
2 soluble solutes comprising the steps of:

3 (a) introducing a saline solution containing sparingly soluble solutes  
4 and nucleation crystals to the high pressure side of a first semi-permeable  
5 membrane barrier to produce a retentate stream on the high pressure side of  
6 the first semi-permeable membrane barrier, and a permeate solution on the low  
7 pressure side of the first semi-permeable membrane barrier containing reduced  
8 concentrations of the sparingly soluble solutes;

9 (b) introducing the permeate solution produced on the low pressure  
10 side of the first semi-permeable membrane barrier to the high pressure side of  
11 a second semi-permeable membrane barrier to produce a second retentate  
12 stream on the high-pressure side of the second semi-permeable membrane  
13 barrier, and a product solution on the low pressure side of the second semi-  
14 permeable membrane barrier with substantially lower concentrations of  
15 sparingly soluble and soluble solutes compared to the saline solution initially  
16 introduced in step (a);

17 (c) separating the retentate stream rejected by the first semi-  
18 permeable membrane barrier into a majority fraction solution containing a  
19 majority of the nucleation crystals and a minority fraction solution containing a  
20 minority of the nucleation crystals;

21 (d) returning the majority fraction solution directly to the saline  
22 solution that is introduced to the high pressure side of the first semi-permeable  
23 membrane barrier;

24 (e) separating the minority fraction solution into: (i) a first-fraction  
25 solution with a higher level of suspended solids, and (ii) a second-fraction  
26 solution with a lower level of suspended solids;

27 (f) returning a portion of the first-fraction solution with a higher  
28 level of suspended solids to the saline solution that is introduced to the high  
29 pressure side of the first semi-permeable membrane barrier; and

30 (g) returning the second retentate stream to the saline solution that  
31 is introduced to the high pressure side of the first semi-permeable membrane  
32 barrier.

1 19. The method of claim 18 wherein the separation of the minority  
2 fraction solution in step (e) is accomplished using a gravity settling tank,  
3 centrifuge, hydrocyclone or filter.

1 20. The method of claim 18 wherein the first-fraction solution with a  
2 higher level of suspended solids is further split into (i) a discharge fraction and  
3 (ii) a recovery fraction with the recovery fraction being returned and introduced  
4 into the saline solution that is introduced into the high pressure side of the first  
5 semi-permeable membrane barrier.

1 21. The method of claim 18 wherein the second-fraction solution with  
2 a lower level of suspended solids is further split into (i) a discharge fraction and  
3 (ii) recovery fraction with said recovery fraction being returned and introduced  
4 into the saline solution that is introduced into the high pressure side of the first  
5 semi-permeable membrane barrier.

1 22. The method of claim 18 wherein a fraction of the discharge  
2 fraction is combined with the product stream produced on the low pressure side  
3 of the second semi-permeable membrane barrier to effect a reduction in the  
4 agronomic sodium adsorption ratio of said solution.

1 23. The method of claim 18 wherein the initial saline solution is  
2 heated.

1           24.     The method of claim 18 wherein saline solution is introduced into  
2     the high pressure side of the second semi-permeable membrane barrier which  
3     does not pass through the first semi-permeable membrane barrier.

1           25.     The method of claim 18 wherein the retentate stream rejected by  
2     the first semi-permeable membrane barrier containing a majority of the  
3     nucleation crystals is desupersaturated before the solution is returned to the  
4     high pressure side of the first semi-permeable membrane barrier.

1           26.     The method of claim 18 wherein the first semi-permeable  
2     membrane barrier is selected from the class of nanofiltration membranes.

1           27.     The method of claim 18 wherein the second semi-permeable  
2     membrane barrier is selected from the class of reverse osmosis membranes.

1           28.     The method of claim 18 wherein the first semi-permeable  
2     membrane barrier is contained in tubular membrane modules.

1           29.     The method of claim 18 wherein the second semi-permeable  
2     membrane barrier is contained in spiral-wound membrane elements.

1           30.     The method of claim 18 wherein the sparingly soluble solutes in  
2     the initial saline solution are calcium sulfate and silica.

1           31.     The method of claim 18 wherein the seed nucleation crystals  
2     added upon startup are selected from the group of calcium sulfate, calcium  
3     carbonate, calcium phosphate, and silica.

1           32.     The method of claim 18 wherein the initial saline solution is  
2     water containing between 3,000 and 20,000 mg/L of total dissolved solids.

1           33.     The method of claim 18 wherein the solution produced on the low  
2     pressure side of the second semi-permeable membrane barrier is water  
3     containing less than 500 mg/L of total dissolved solids.

1           34.     The method of claim 18 wherein the water content of the  
2     solution produced on the low pressure side of the second semi-permeable  
3     membrane barrier is greater than or equal to 80% of the water content of the  
4     initial saline solution.

1           35.    The method of claim 18 wherein the initial saline solution is  
2           agricultural drainage water.

1           36.    The method of claim 18 wherein the initial saline solution is  
2           groundwater.

1           37.    The method of claim 18 wherein the initial saline solution is the  
2           brine stream produced in a separate water treatment process.

1           38.    A system for desalinating a solution containing soluble and  
2           sparingly soluble solutes comprising:

3                   (a)    a first semi-permeable membrane barrier having a high-  
4                   pressure side and a low-pressure side for receiving a feed stream on the  
5                   high-pressure side and producing:

6                           a permeate stream on the low-pressure side having reduced  
7                           concentrations of sparingly soluble solutes as compared to the  
8                           feed stream, and

9                           a first retentate stream on the high-pressure side;

10                   (b)   a second semi-permeable membrane barrier having a low  
11                   pressure side and a high-pressure side in fluid communication with, and  
12                   downstream of, the first semi-permeable membrane for receiving the  
13                   permeate stream on the high-pressure side and producing:

14                           a second retentate stream on the high-pressure side, and

15                           a product water stream on the low-pressure side having  
16                           substantially lower concentrations of sparingly soluble and  
17                           soluble solutes compared to the feed stream; and

18                   (c)   means for separating solids from the first retentate  
19                   stream into a first fraction solution having a higher level of suspended  
20                   solids and a second fraction solution with a lower level of suspended  
21                   solids, said solid separating means in fluid communication with the high-  
22                   pressure side of the first semi-permeable membrane.

1           39.    The system of claim 38 wherein said separating means is  
2           selected from the group consisting of: a gravity settling tank, a centrifuge, a  
3           hydrocyclone and a filter.

1           40.    The system of claim 38 further comprising means for joining a  
2           stream from the solid separating means and a stream from the high-pressure  
3           side of the second semi-permeable membrane with the feed stream.

1           41.    The system of claim 38 further comprising:  
2                   (d)    means for separating the first retentate stream into a  
3           majority fraction solution and a minority fraction solution upstream of said  
4           solid-separating means, wherein said minority fraction solution is in fluid  
5           communication with said solid separating means and said majority fraction  
6           solution is in fluid communication with said high-pressure side of said first semi-  
7           permeable membrane barrier.

1           42.    The system of claim 38 further comprising:  
2                   (d)    means for passing a portion of the feed stream directly to  
3           the high-pressure side of the second semi-permeable membrane.

1           43.    The system of claim 38 further comprising:  
2                   (d)    means for heating the feed stream.

1           44.    The system of claim 38 further comprising means for splitting  
2           said first fraction solution into a high-solid recycle stream and a high-solid  
3           discharge stream.

1           45.    The system of claim 38 including means for splitting said second  
2           fraction solution into a low-solid recycle stream and a low-solid discharge  
3           stream.

1           46.    The system of claim 41 further including desupersaturating  
2           means to receive said majority fraction solution and said second fraction  
3           solution.

1           47.    The system of claim 46 wherein said desupersaturating means is  
2           a stirred vessel.

1           48.    The system of claim 44 further including adjustment means for  
2           controlling the agronomic sodium absorption ratio of said product water stream,  
3           said adjustment means allowing a controlled amount of said high-solid  
4           discharge stream to be added to said product water stream.